Chemical evolution on smallest scales

~ hints from observations of dwarf galaxies ~

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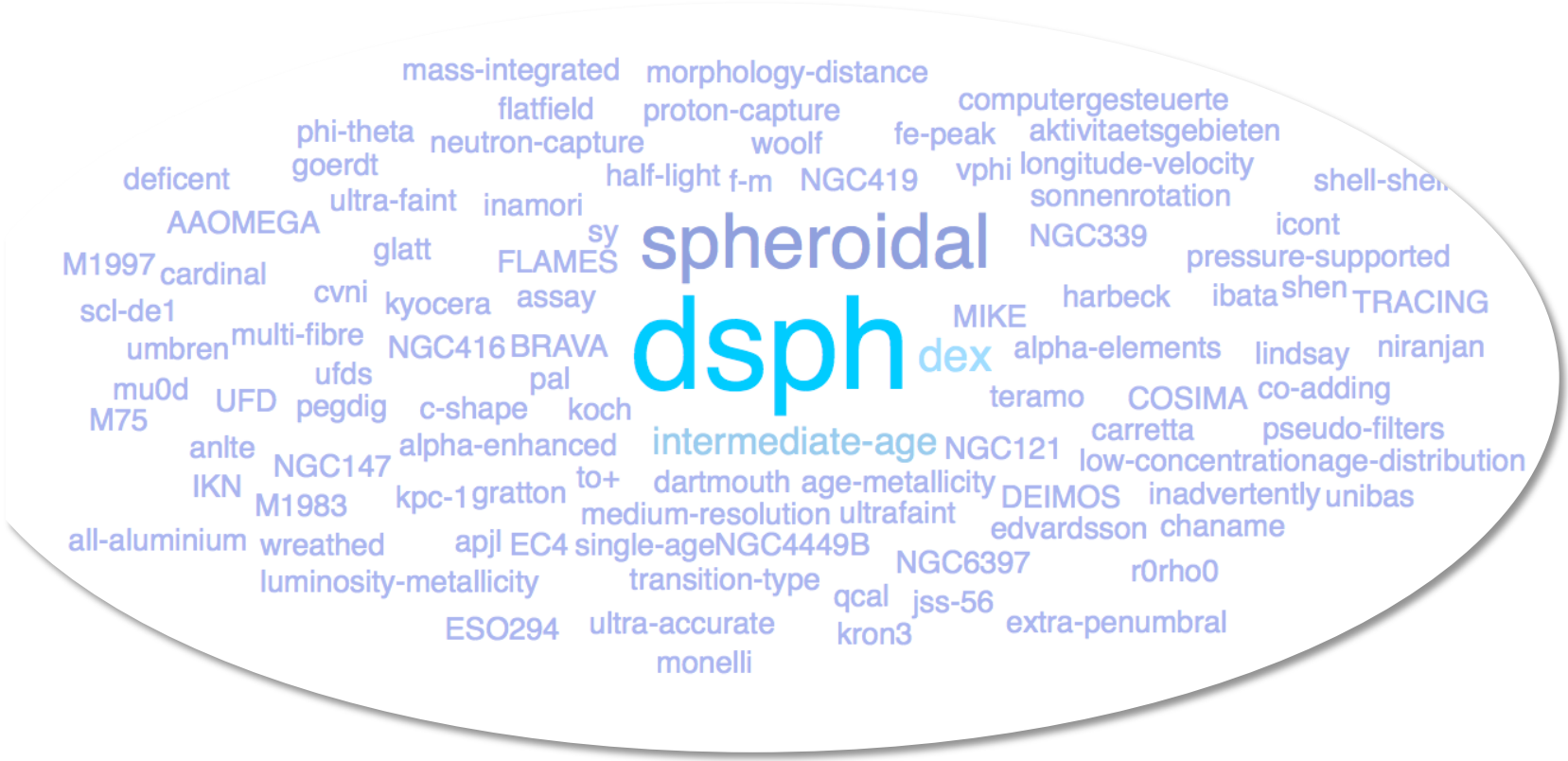
S. Feltzing (Lund), **F. Matteucci** (Trieste)

Word Clouds

(@ ADS Labs)

Koch, A. (2002 – present)



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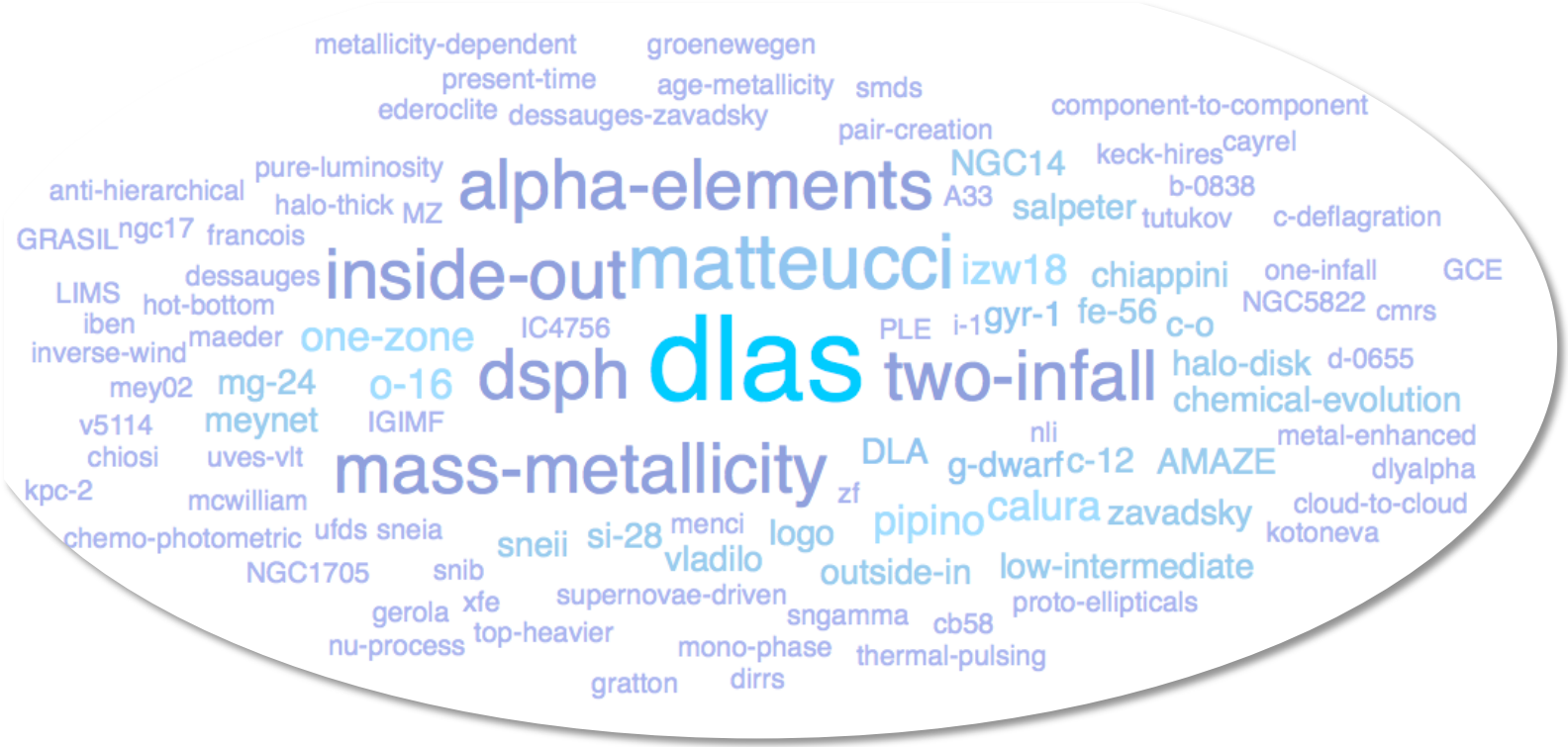

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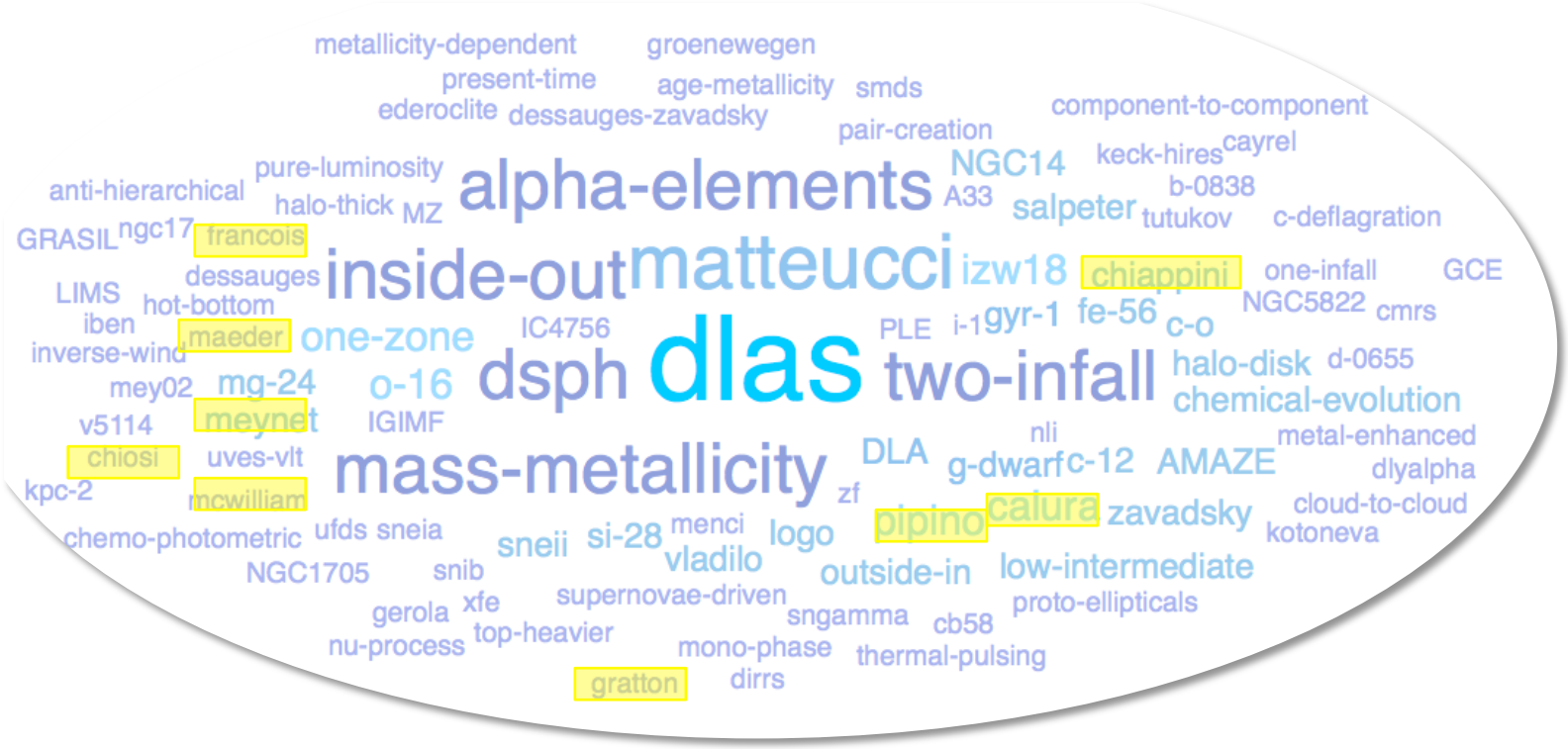

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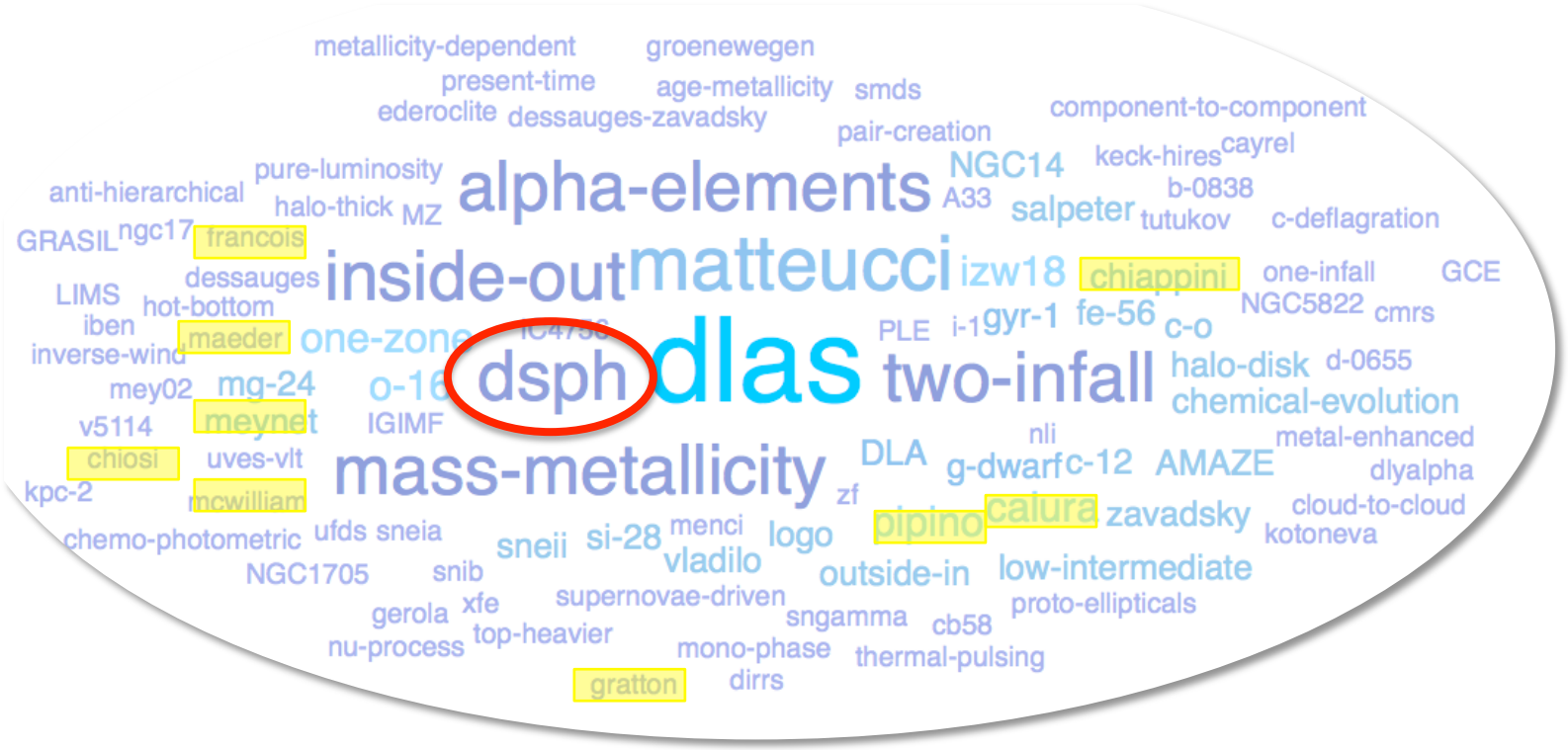
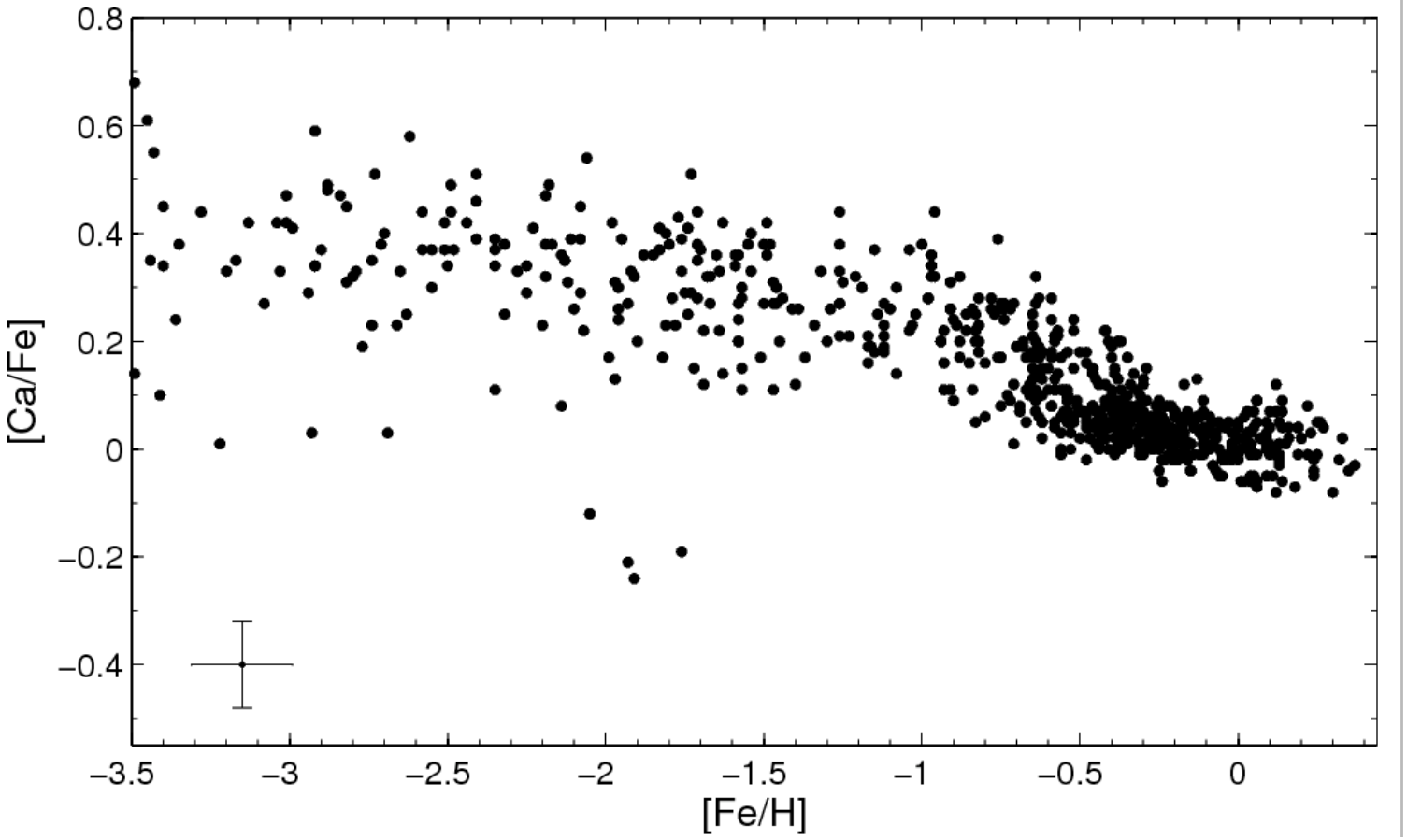


dSph abundances (HR)



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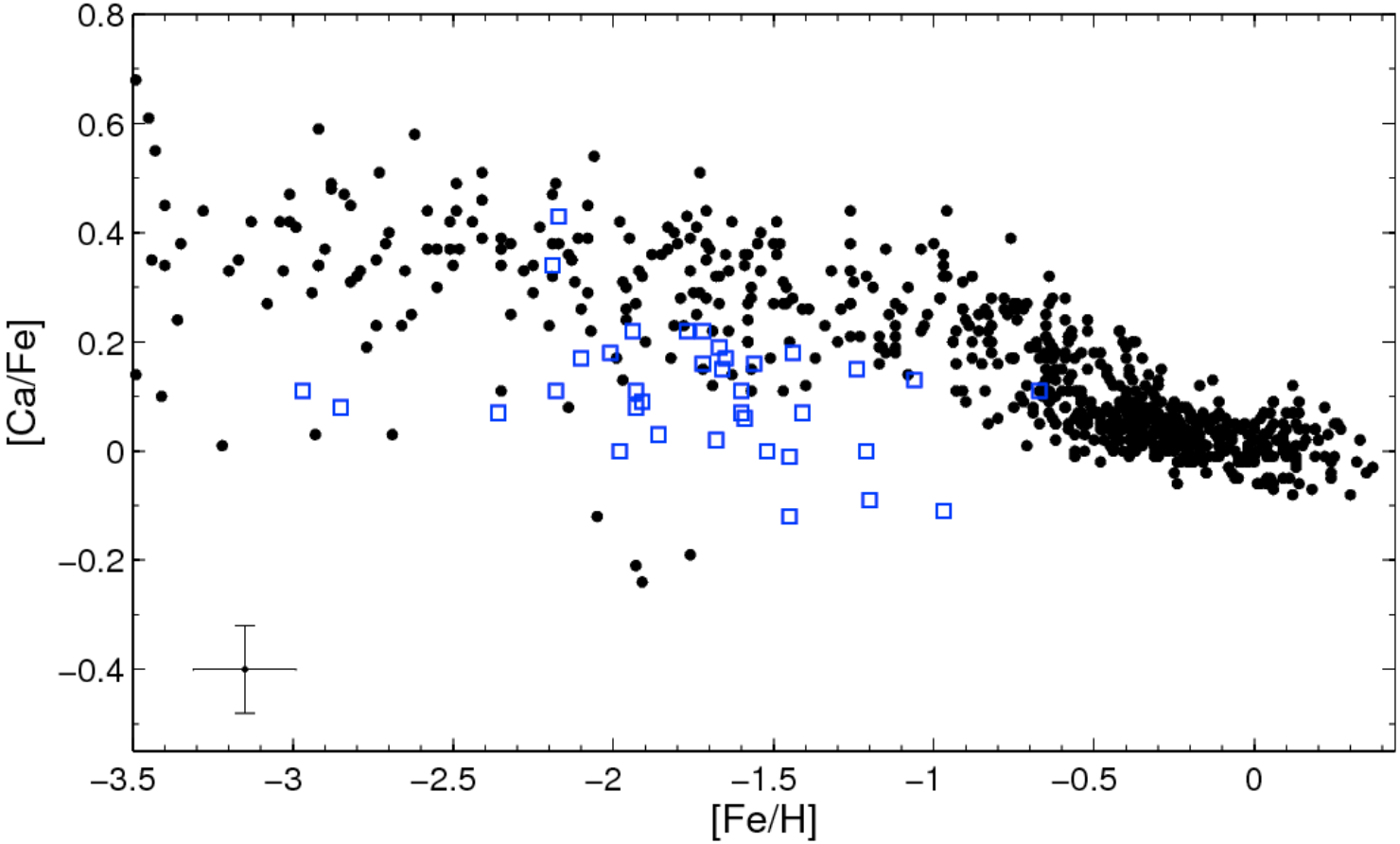

Shetrone et al. (2001, 2003): 5 dSphs

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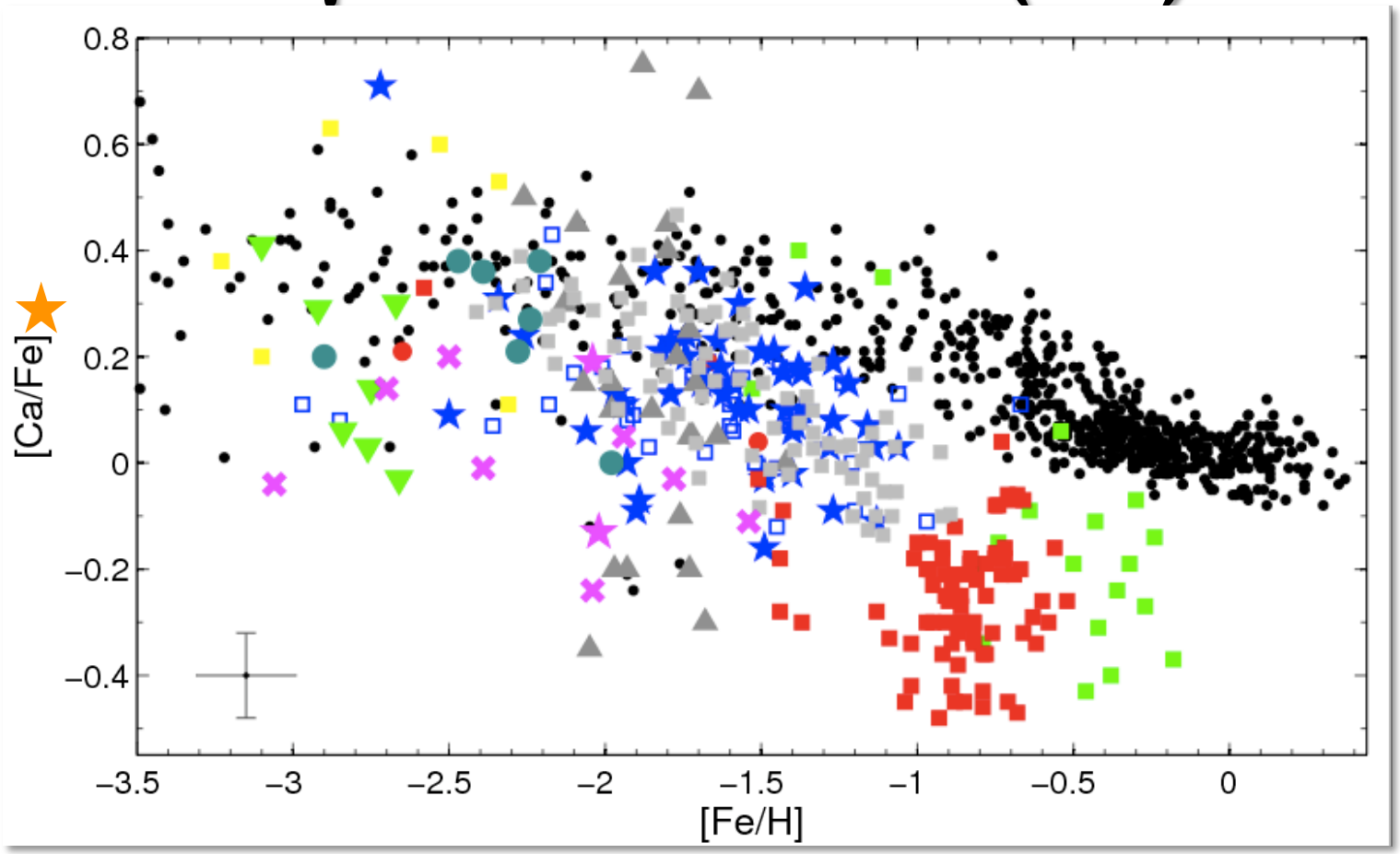

Shetrone et al. (2001, 2003): 5 dSphs

Sadakane et al. (2004): Ursa Minor

Monaco et al. (2005): Sagittarius

Koch et al. (2007, 2008, 2009): Carina

Letarte (2010): Fornax

Koch et al. (2008): Hercules

Frebel et al. (2010): Sculptor

Shetrone et al. (2008): Leo II

Frebel et al. (2009): Coma Ber, Ursa Major

Aoki et al. (2009): Sextans

Hill et al. (in prep.): Sculptor

Cohen & Huang (2009): Draco

Feltzing et al. (2009): Boo I

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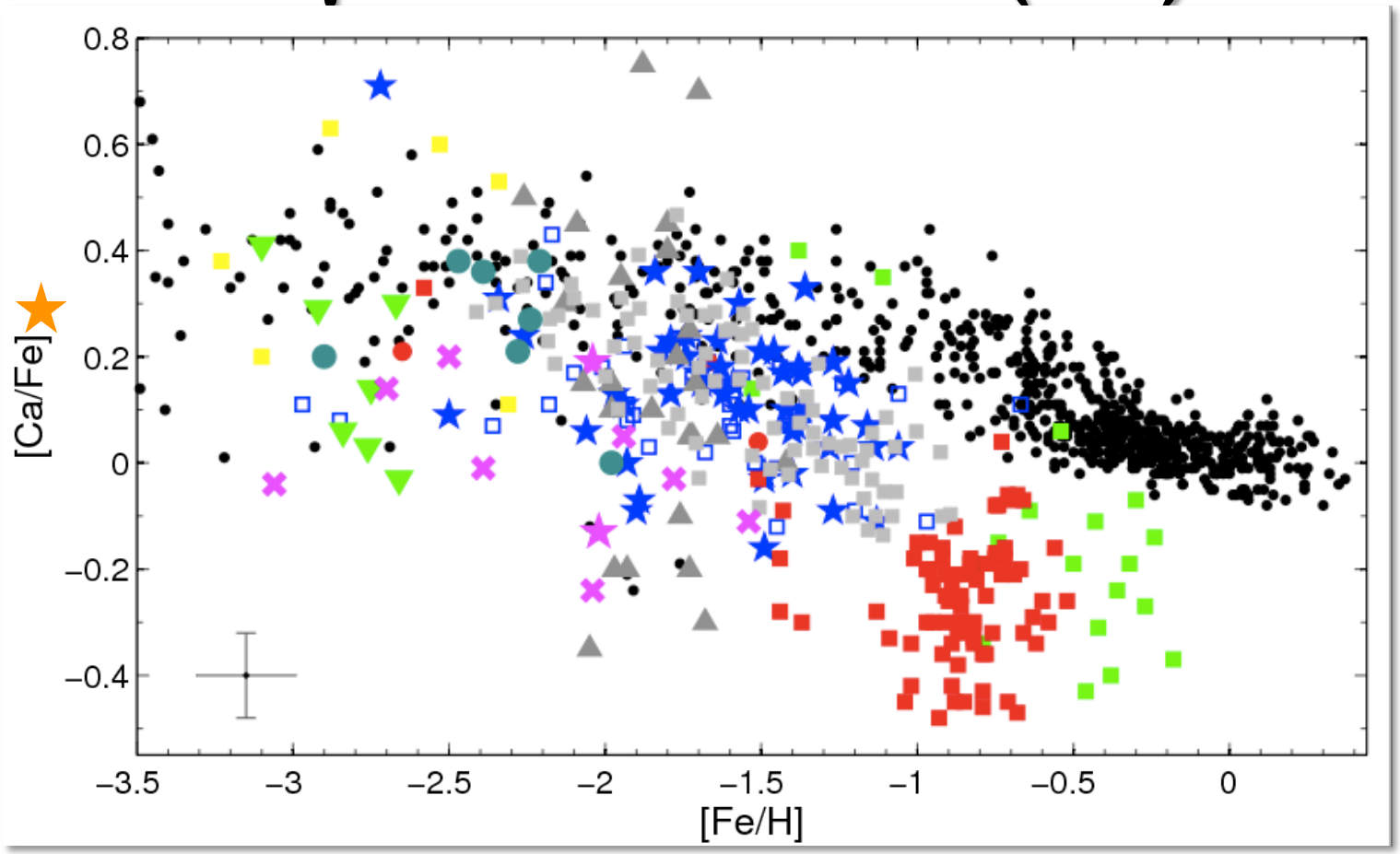

Different turnovers (“knee”) dependent on star forming efficiencies. (Ultrafaint) dwarfs are very inefficient; also large scatter at metal-poor end.

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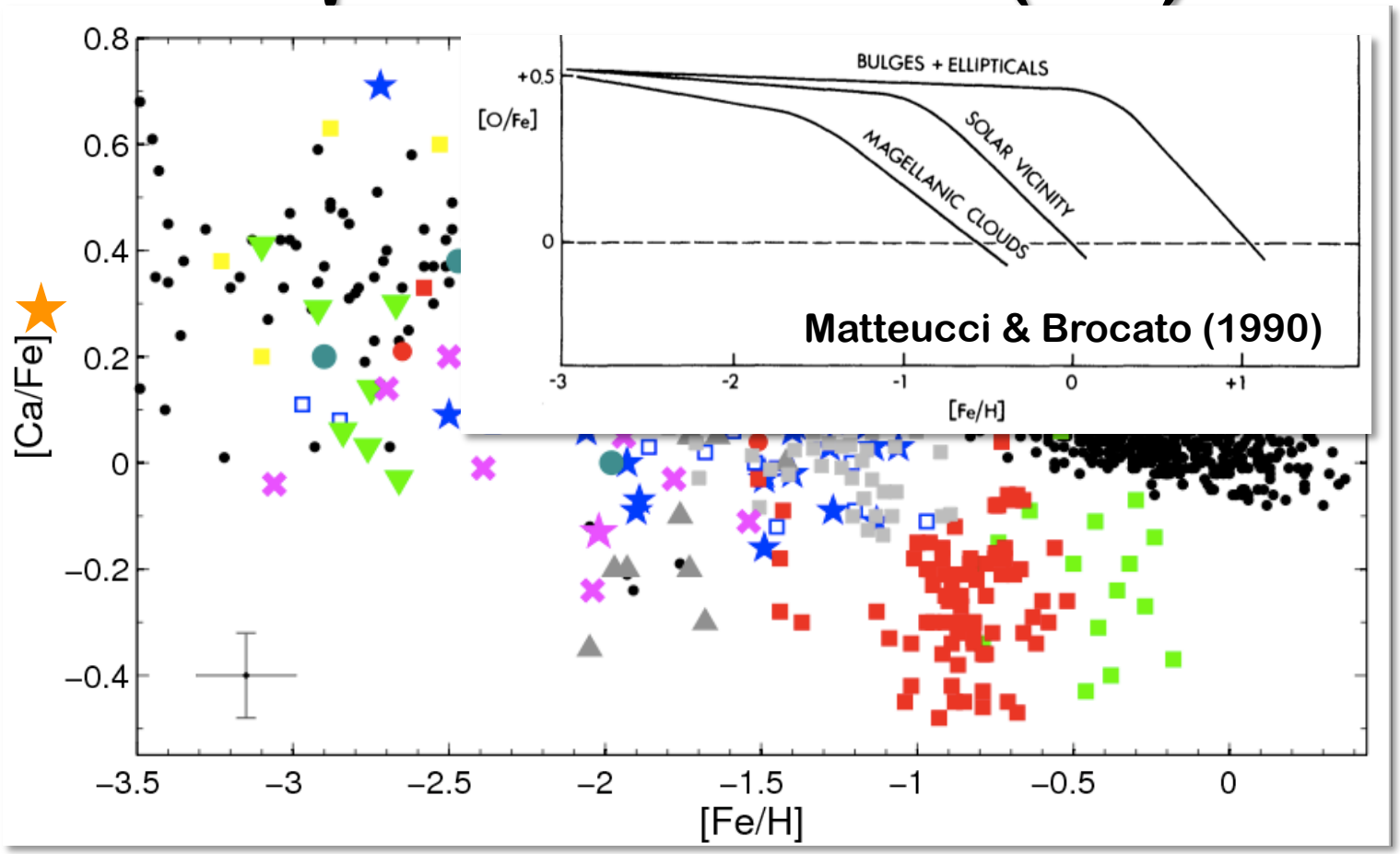

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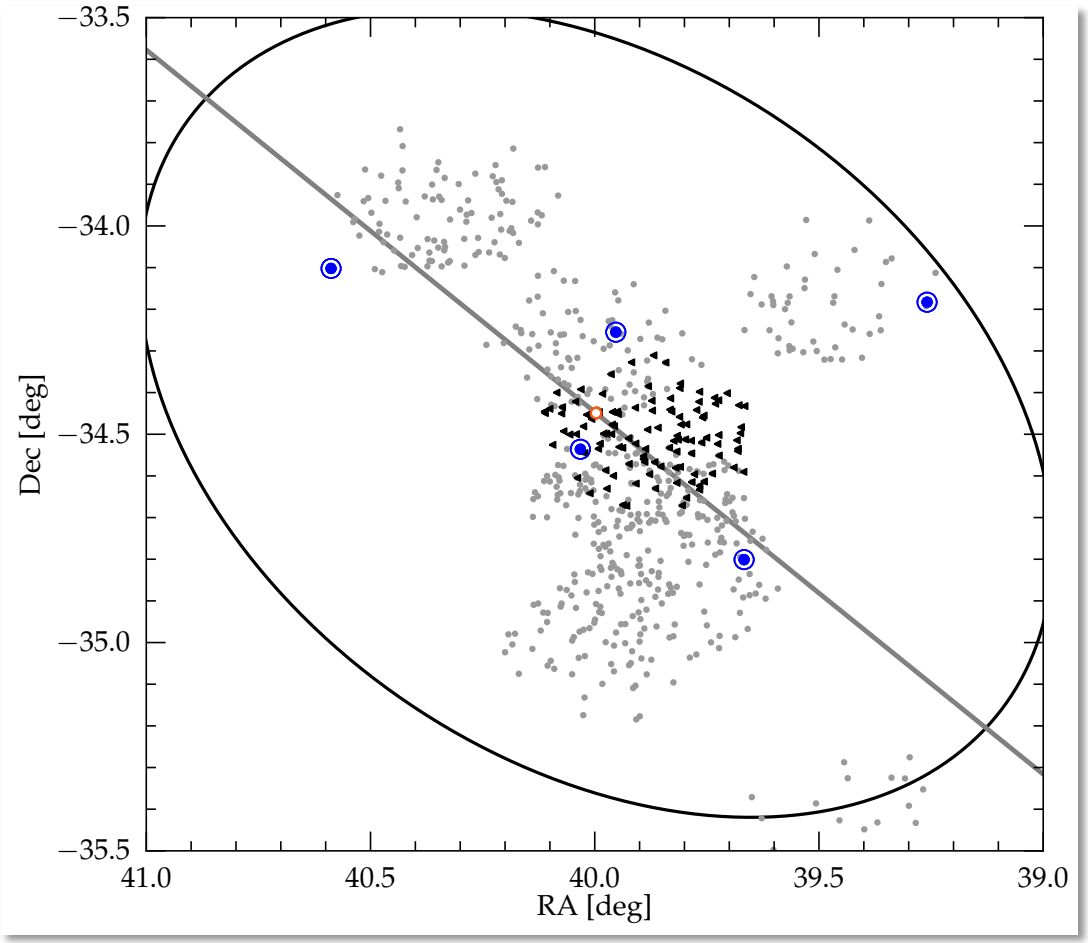
Fornax – spectroscopic coverage

M_V = -13.2 – 2nd luminous after Sgr.

Continuous star formation history (from CMDs; Grebel 2002).

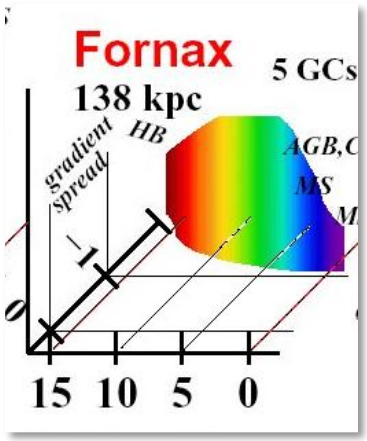
So far, mainly studies of inner regions.



Our data (VLT/FLAMES, HR21): outer parts (Ph.D. B. Hendricks)

- CaT (Battaglia et al. 2006)
- HR (Letarte et al. 2010)
- GCs (Letarte et al. 2006)

- HR (Hendricks et al. in prep.)



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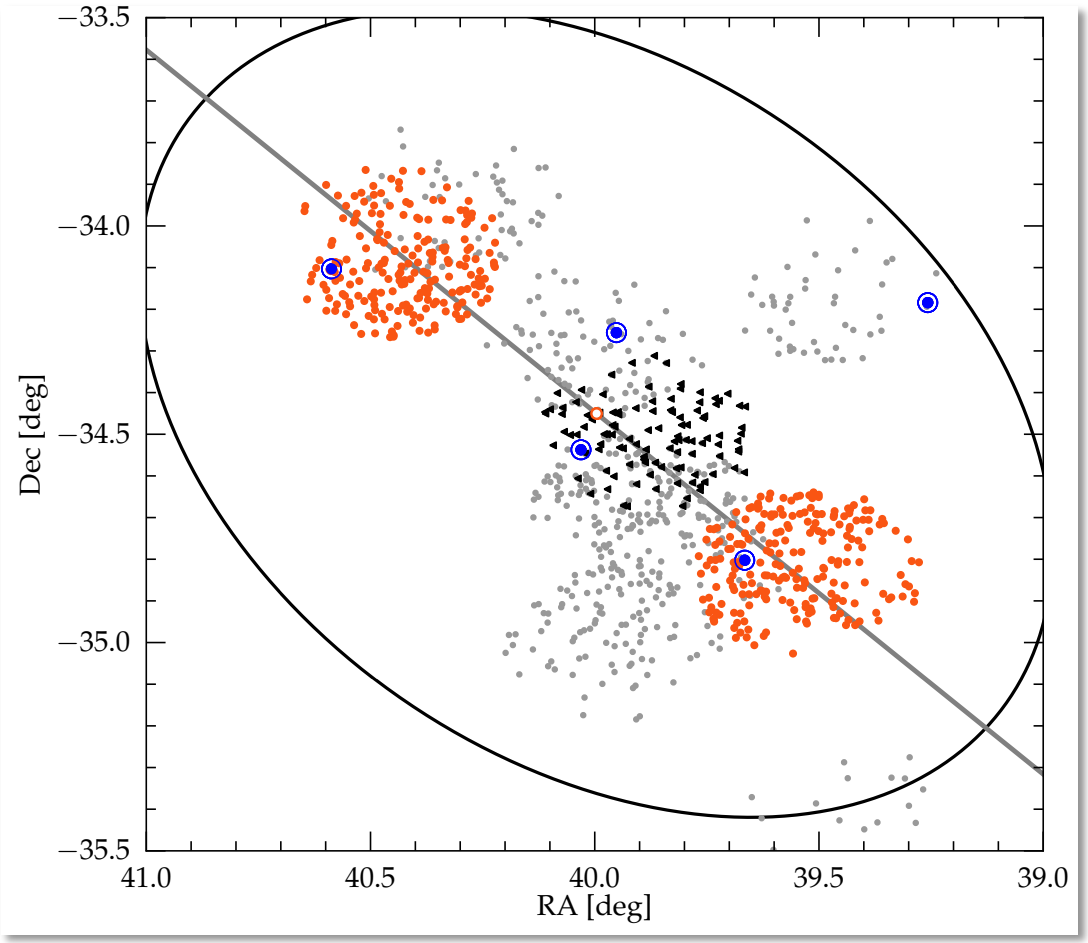

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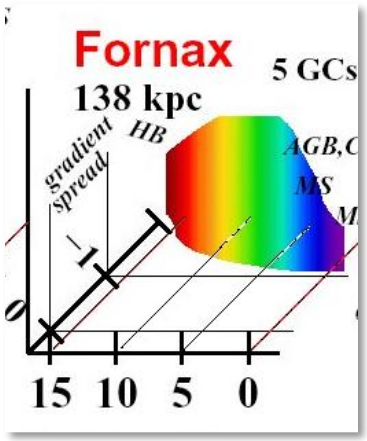
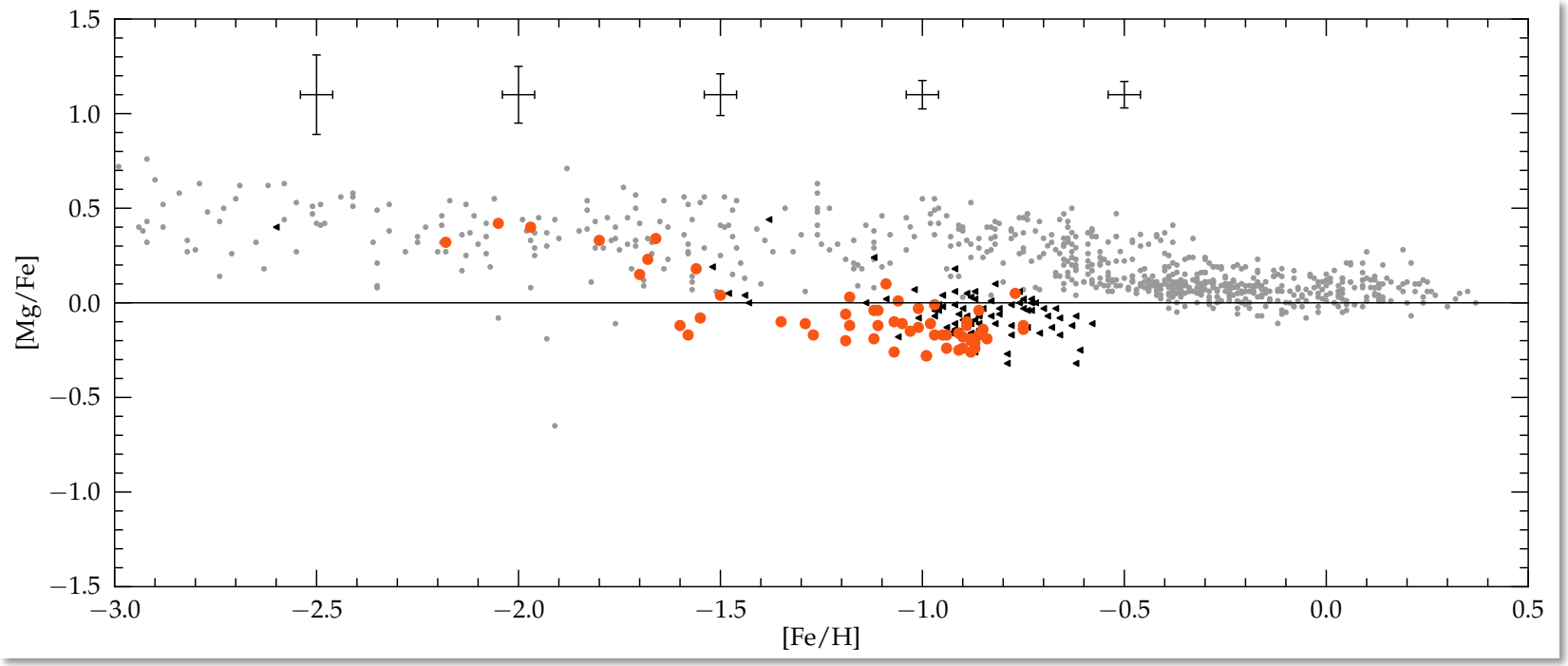


Fornax – a metal-weak knee



B. Hendricks et al. in prep.

- Metal poor (-1.8 dex) location of the "knee" from toy model (e.g., Cohen & Huang 2009 [Dra]).
- ~ consistent for Mg, Si, Ti, and <α>.
- Contrast to extended SFH.
  Cf. Scl, ~same turnover, but Mv = -11.
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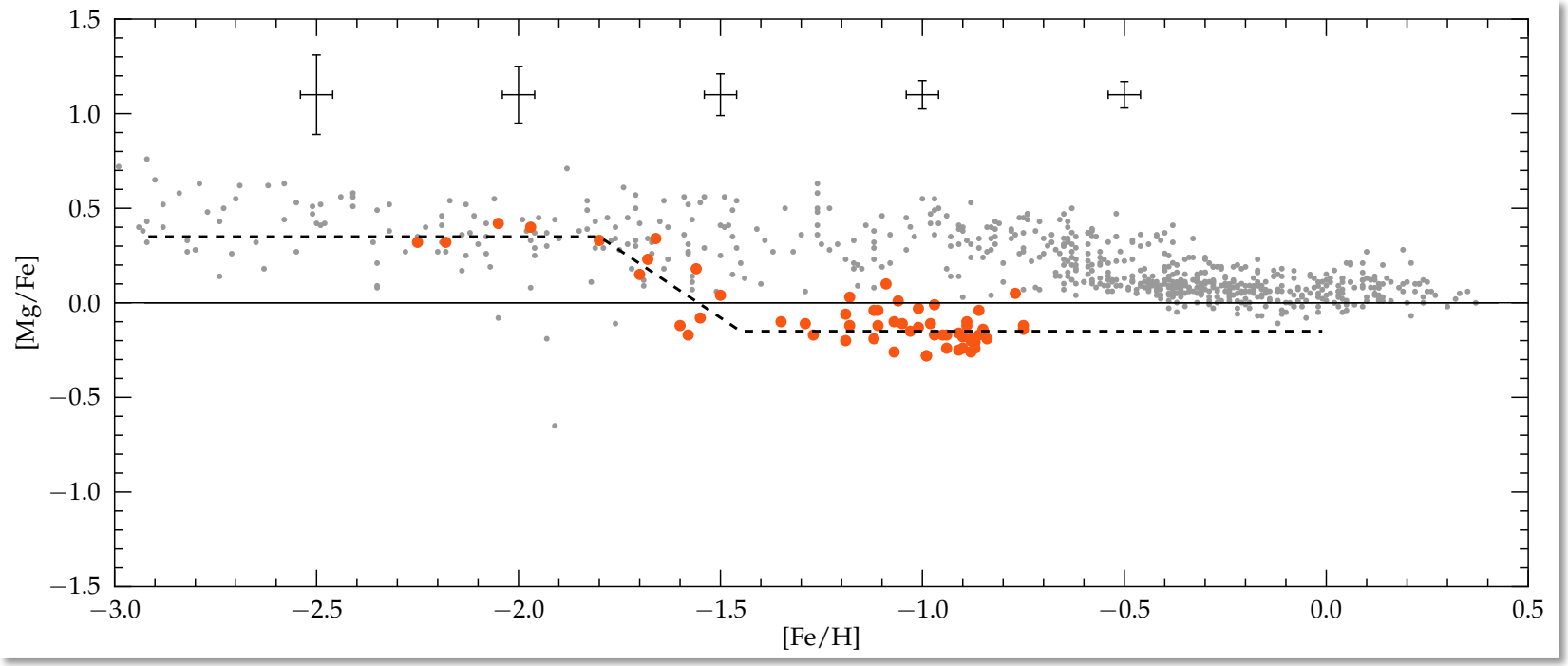

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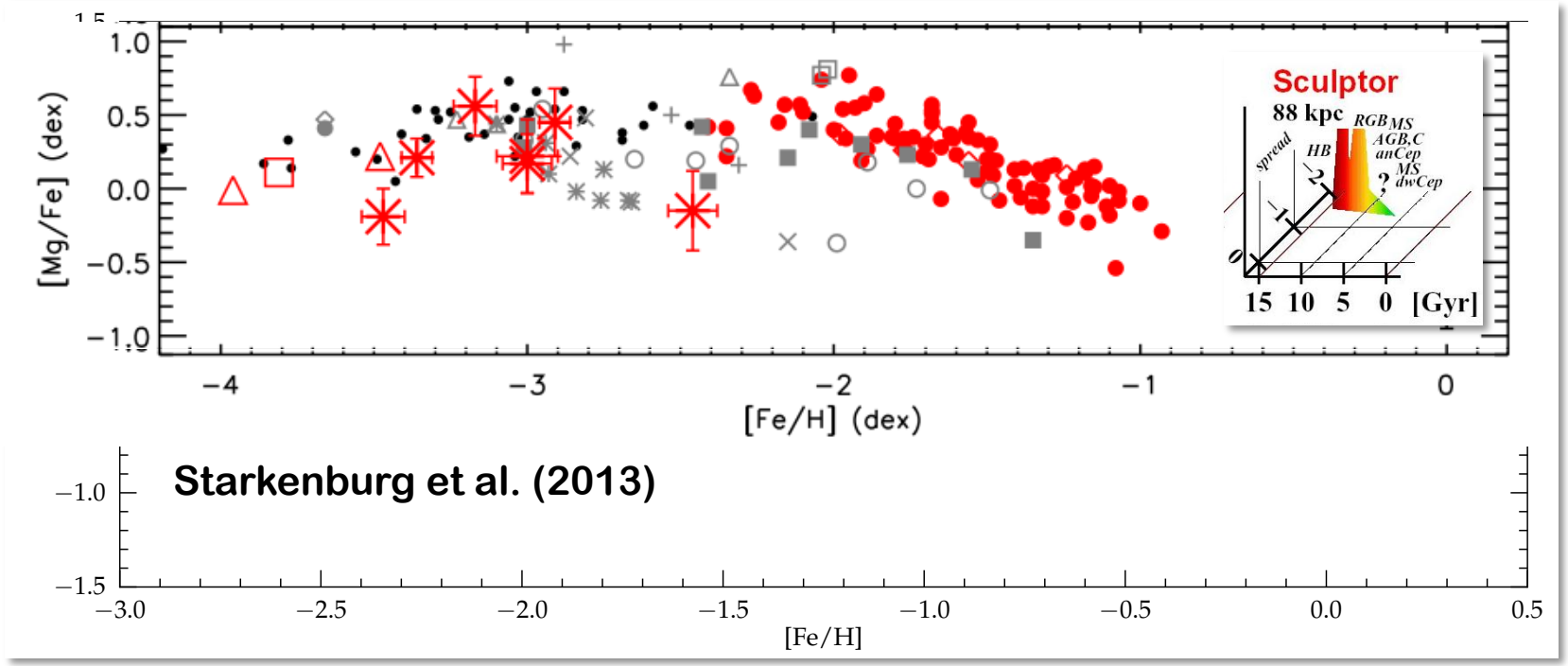

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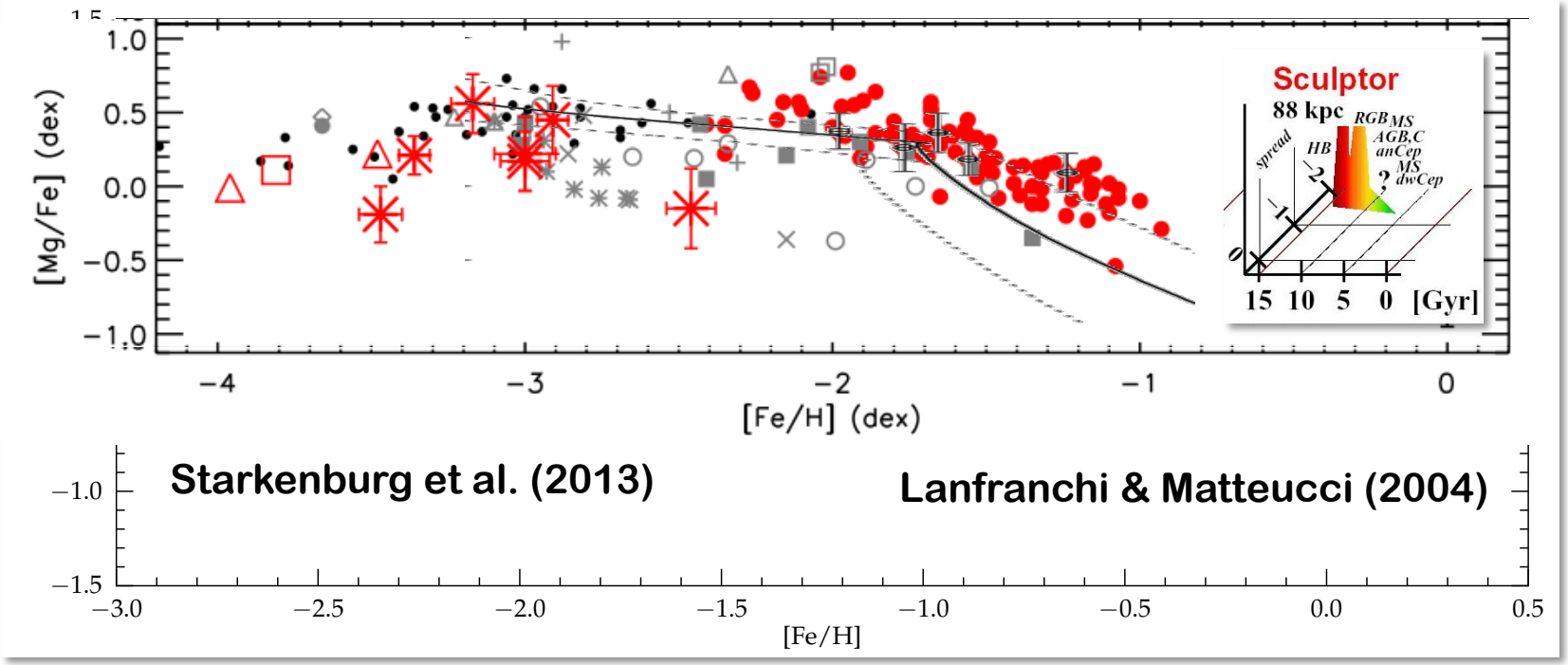

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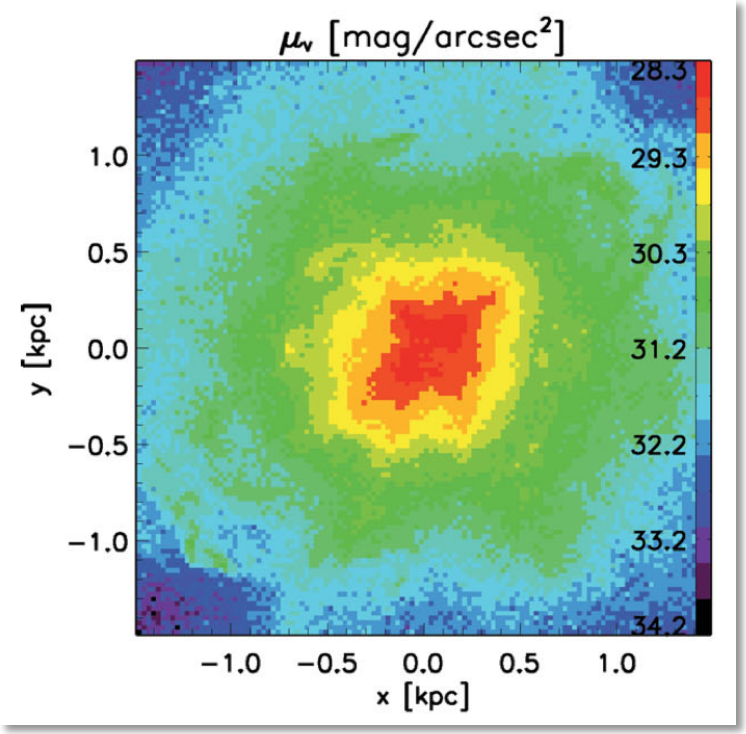
Fornax – an accretion origin?



Outer regions formed from accreted star clusters?

(→ Talk by R. Gratton)

→ $[Fe/H]_{GC}$ (outer) ~ -2.1…-2.5 dex (see also Larsen 2012).

→ Kinematically feasible (increasing σ with decr. [Fe/H])

→ Consistent with models (Assmann et al. 2013)

→ Fornax started less massive and only gained later on ?!

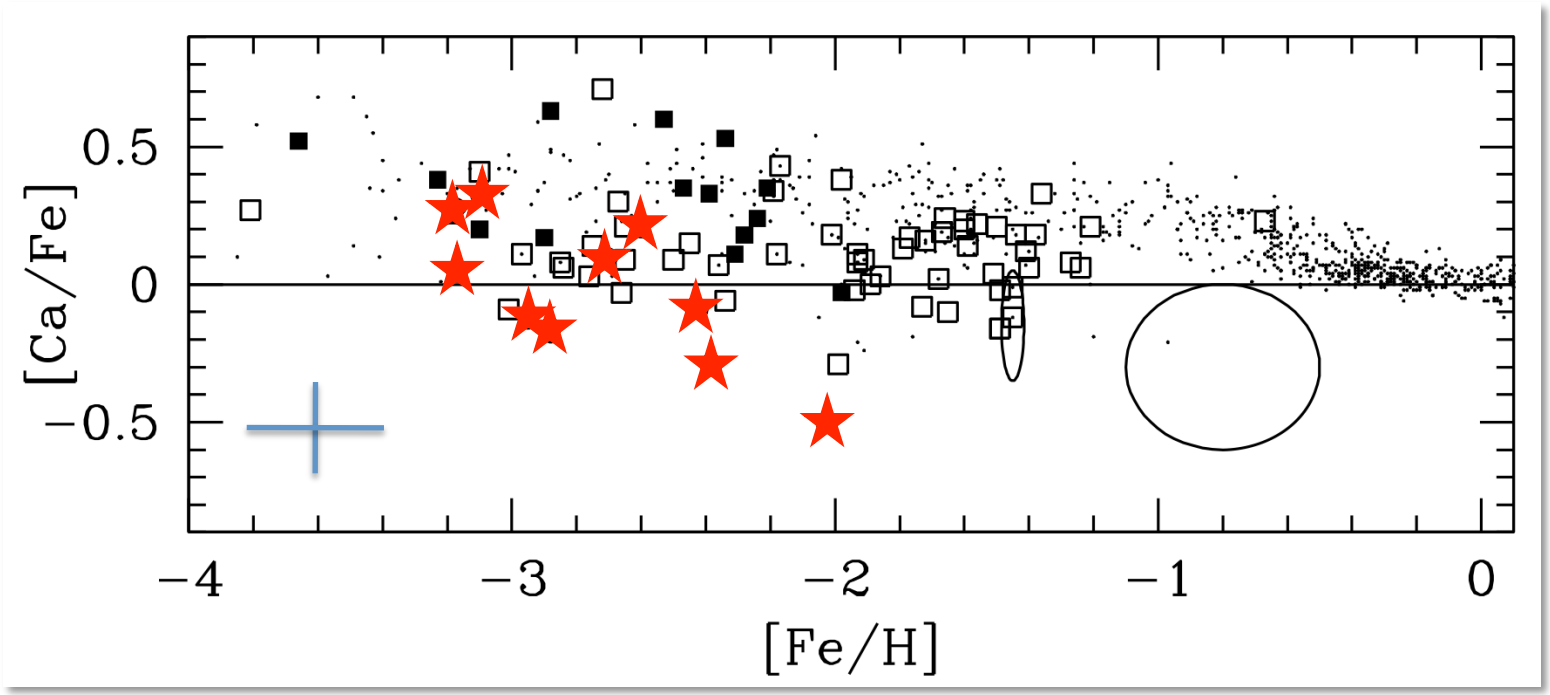
Hercules – element ratios

MIKE and FLAMES spectroscopy

- very large spread in Fe *and* Ca

- anomalously high [Mg/Ca] and [Co/Cr] ratios

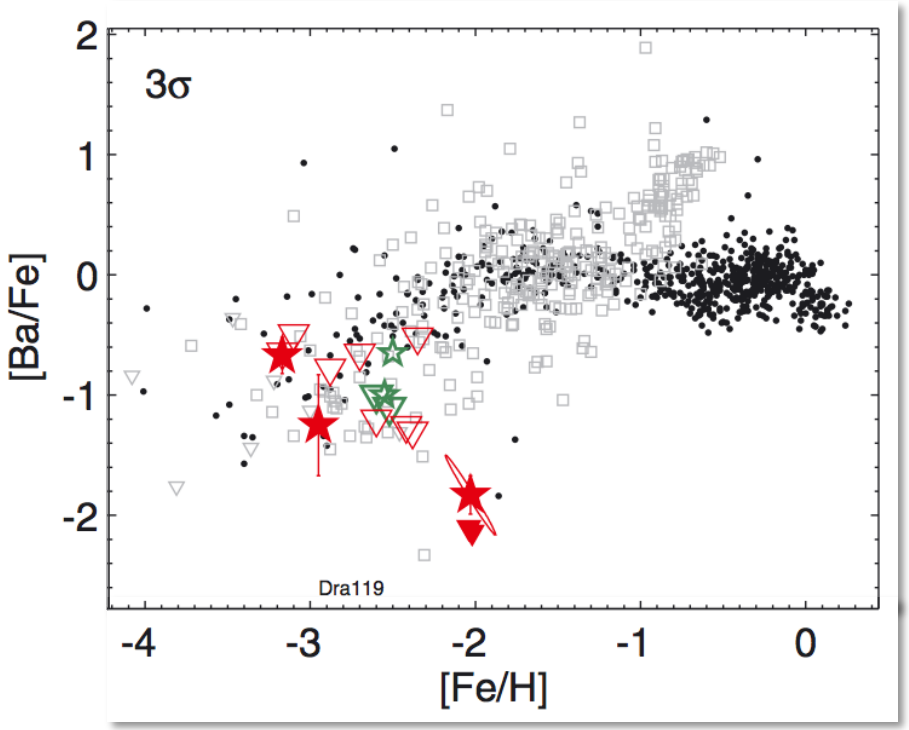
→ enrichment by only a few, massive (~35 M_o) SNe II.



(Koch et al. 2008; Adèn, AK, et al. 2011):

Hercules – n-capture elements

- Her stars are strongly depleted in Ba (Sr, Eu); Only upper limits for Ba.
- So far seen in a few halo stars, Dra 119 and 2 UFDs (Fulbright et al. 2004; Feltzing et al. 2009; Simon et al. 2010)



AK et al. (2013)

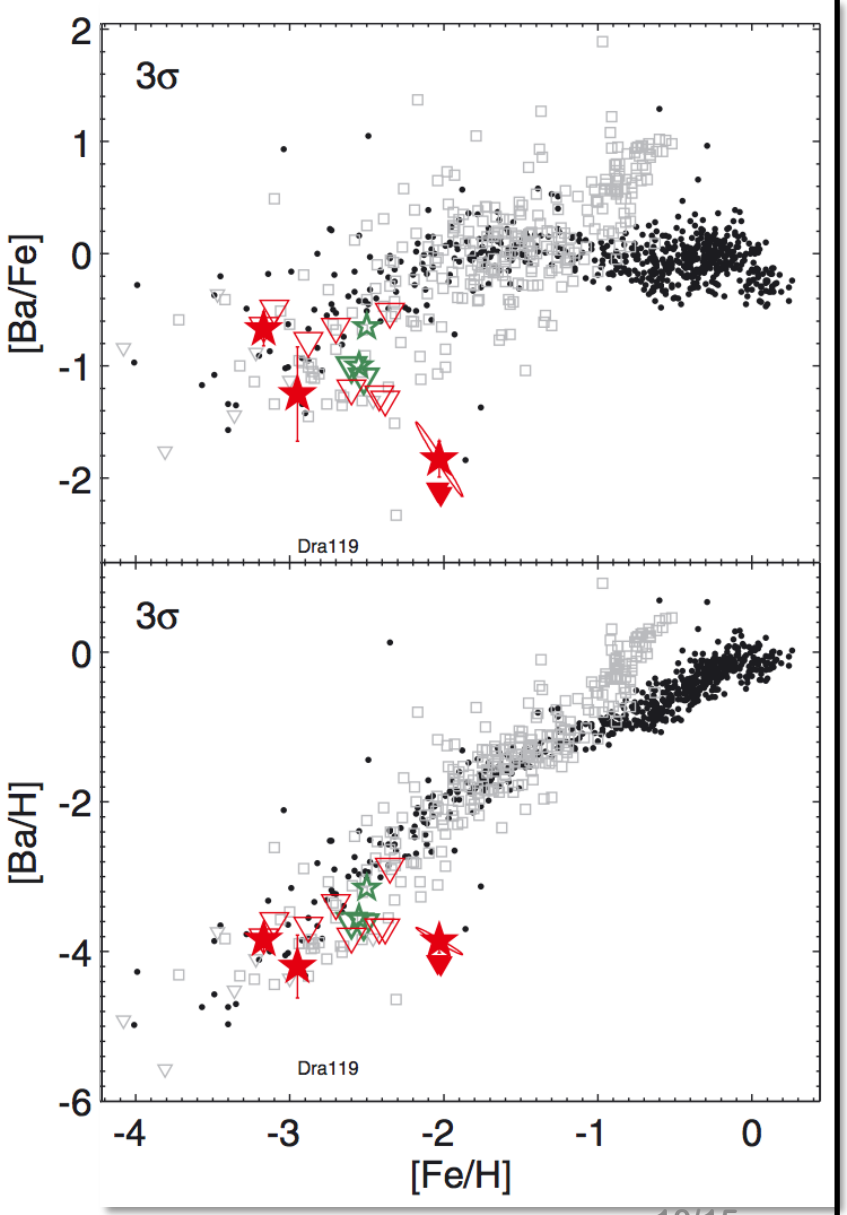
Element anomalies in Hercules

Stochastic SF?

M_{tot} = 7 x 10^6 $M_\odot$ and M/L = 330
implies $M_* \sim 40000\ M_\odot$
(Martin et al. 2008)

Incomplete sampling of high-mass end of IMF in small-scale SF events
Probably only 1-3 massive SNe II influenced the Her stars:

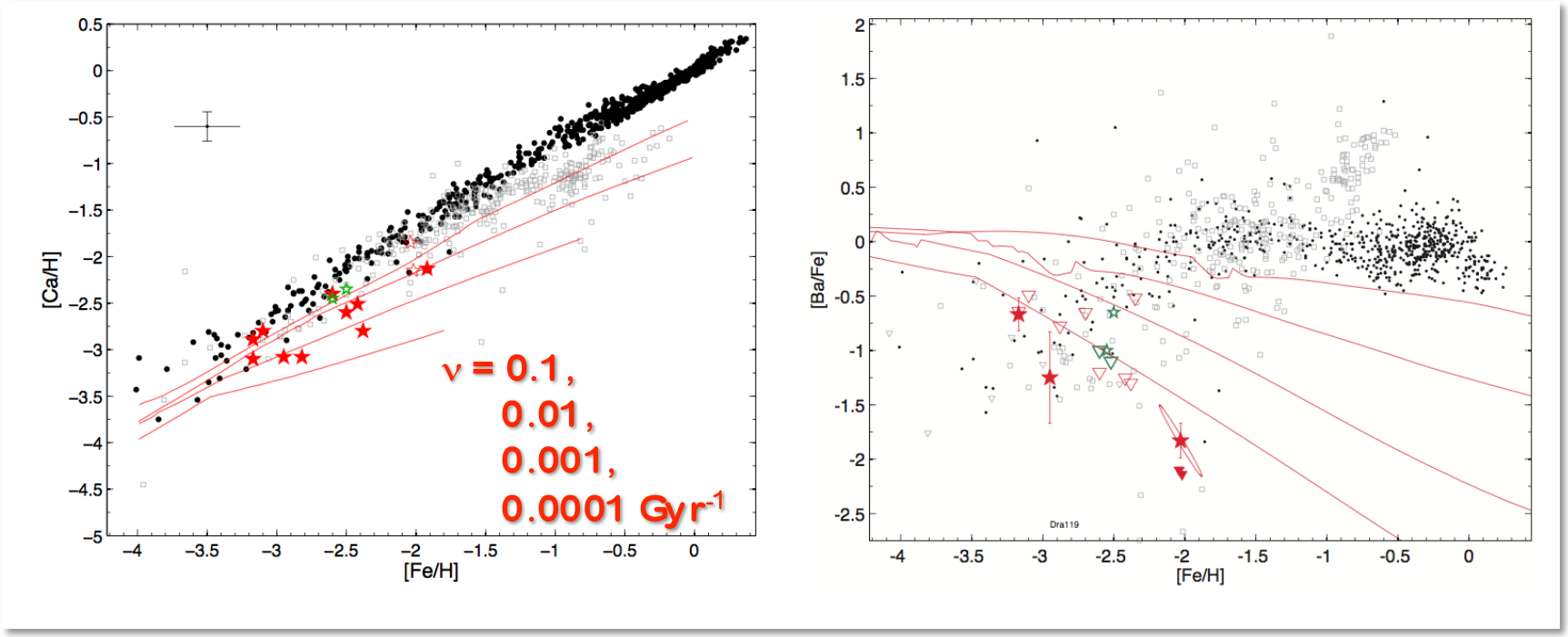
- [high Mg/Ca]
- initial [Ca/Fe] ~ 0.4
- trace amounts of r-process
- later SF –> Fe contributions and Fe spreads



Star formation in Hercules

Weak knee → low star formation efficiency
→ SNe Ia already at low metallicities

Problem: models fail to simultaneously fit
α- and n-capture elements.



F. Vincenzo, after Lanfranchi & Matteucci (2004); Cescutti et al. (2006)

Star formation in Hercules

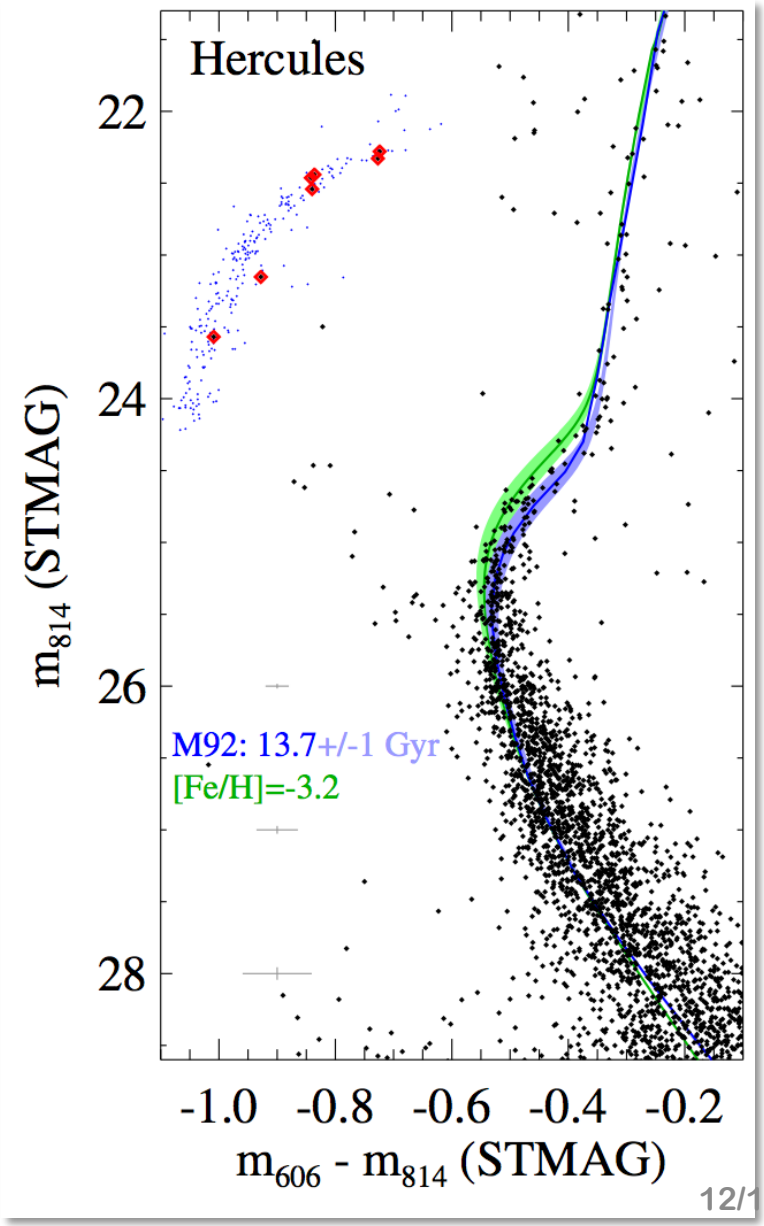
Brown et al. (2012):

- 10% of stars are younger by 1-2 Gyr. They lie at the metal-rich tail.

D. Weisz (priv. comm.):

- (20 ± 10)% have ages of 8 – 10 Gyr.

Problem: How can we have extended SF and chemical evolution with no significant Ba-enrichment?!



(no) Ba in Hercules

- Ba at lowest metallicity from *r*-process ([Fe/H] > -3.2).

→ some sources of *r* not operational in Her?
Only certain SNe masses favored?
Inhomogeneous mixing?

- Later on, Ba in *s*-process → AGB

→ Substantial fraction of blue stragglers and ***binaries***,
f_b ~ 35 – 60% (T. Brown, priv. comm.)

Hercules - binaries

Binaries can affect chemical evolution ***(→ Talk by A. Maeder)*****:**

Roche lobe overflow in *close* binaries

→ AGB envelope removed

→ inhibits thermal pulses

→ no s-process!

(Izzard et al. 2004, 2006;

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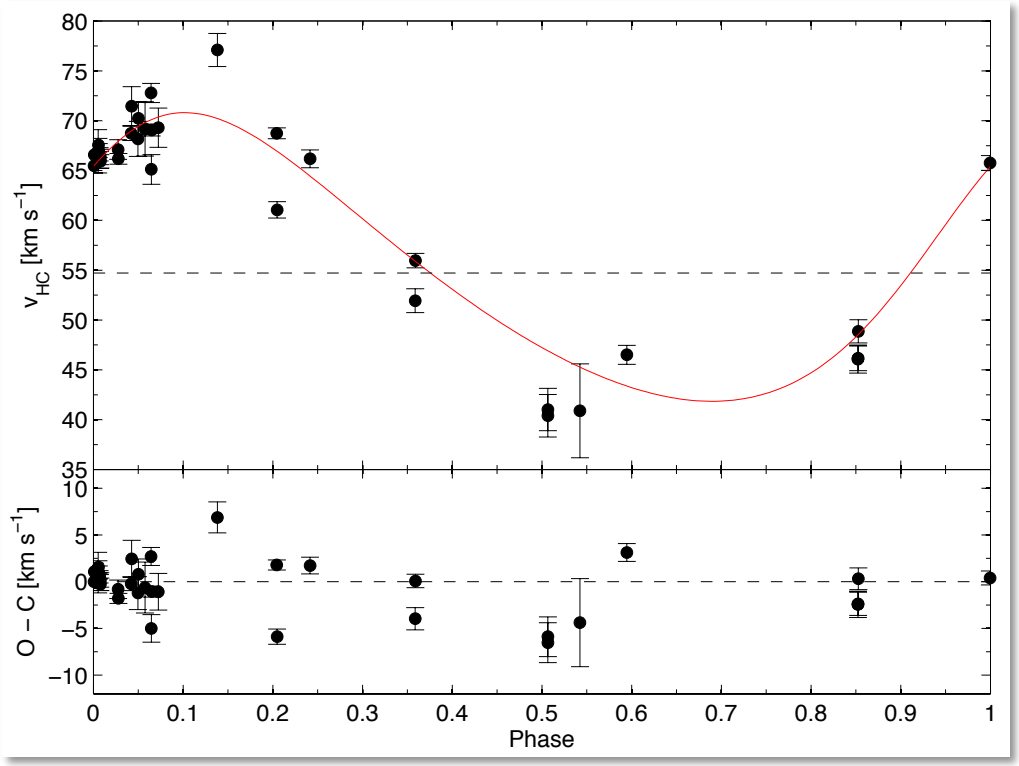
Indeed: RV variations in the red giant Her-3.

P = 135 d

e = 0.18

$a_p \sin i = 38\ R_\odot$

$m_s > 0.38\ M_\odot$



Koch, Hansen, et al., in prep.

Summary

- dSphs in general are affected by small-scale evolution and every dwarf studied to date has revealed interesting anomalies.
- The particular cases have shown:

  -- Fornax: SNe Ia contribute at low metallicities. Significant contribution from GCs.

  -- Hercules: Only few, massive SNe. Important role of binaries.

- These small-scale effects need to be accounted for in the models (also: talk by G. Lanfranchi).

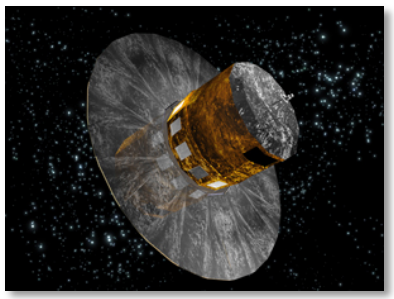
Outlook

(F.M. – the next 60 years)

- Future missions will unravel Galactic structures, substructures, and find many (chemical) oddballs:

  Gaia (Nov./Dec. 2013): radial velocities, PMs

- Dedicated spectroscopic programs, as (Gaia-) follow-up, and also for themselves (complements):

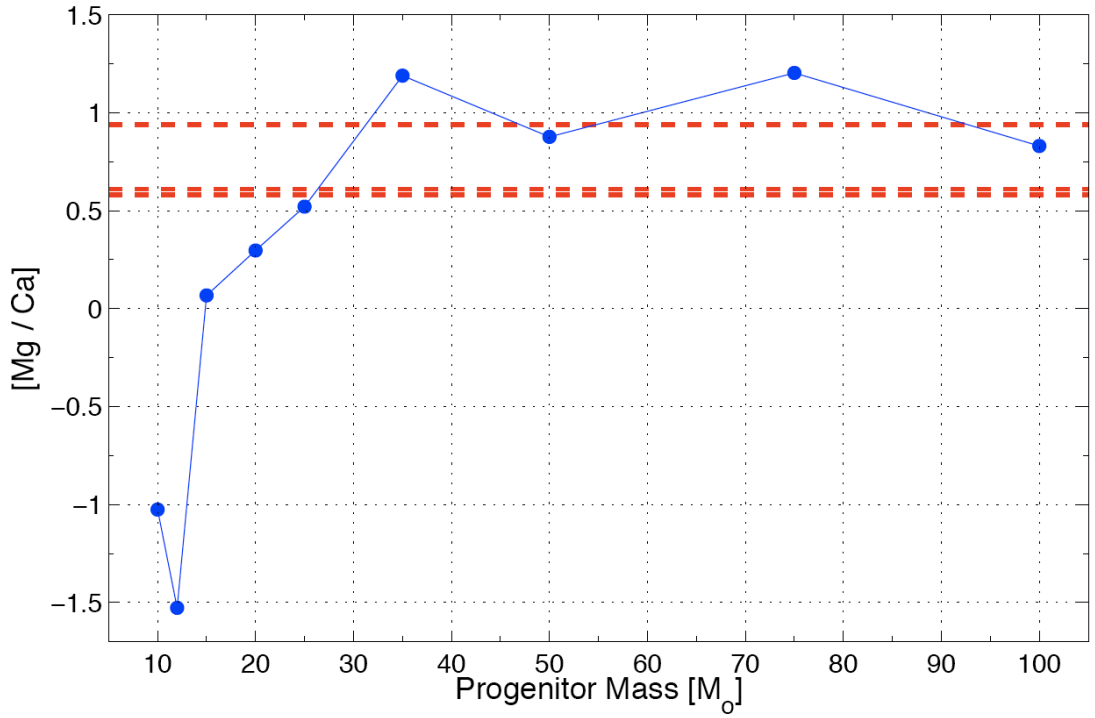


GES (FLAMES/UVES), Jan. 2012
GYES (CFHT; R~20000)
MOONS (VLT; R~5000, 20000)
WEAVE (WHT; R~20000)
4MOST (VISTA; R~5000, 20000): 25 Mio. stars over 5 years, > 2019 (Caffau et al. 2013)

… http://www.ing.iac.es/weave/moslinks.html

Hercules – a small scale hero?

Our high [O, Mg, Si / Ca, Ti] implies M_{prog} ~ 35-50 $M_{\odot}$



Her-2

Her-3, Dra 119

(Heger & Woosley 2008)

Fornax MDF